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TEAM VIGILANCE: THE EFFECTS OF CO-ACTION ON WORKLOAD AND STRESS

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Operator vigilance is a vital concern to the Air Force in regard to cockpit monitoring, air-traffic control, and the supervisory control of unmanned aerial vehicles. A key interest is the performance of teams of observers because of the reliance of military operations on good teamwork. Previous literature has examined the efficacy of team vigilance performance by comparing the frequency of target detections by teams in comparison to those obtained by operators working alone. Team performance has consistently exceeded single-operator performance. The present study replicates this effect and provides the initial experimental investigation of the cost of being a team member. Results indicated that team members worked harder but reported less distress than single operators in the performance of a simulated UAV monitoring task.

Vigilance, or sustained attention, refers to the ability of observers to maintain their focus of attention and to detect infrequent and unpredictable targets over prolonged periods of time (Davies & Parasuraman, 1982). The ability of observers to sustain attention and detect these transient signals is of substantial concern to human factors and ergonomic specialists within the Air Force because of the vital role that vigilance plays with regard to enemy surveillance, cockpit monitoring, air-traffic control, and the supervisory control of unmanned aerial vehicles (Warm, Parasuraman, & Matthews, 2008). Accordingly, the Air Force is engaged in studies to further understand the factors that influence vigilance performance and to evaluate the effectiveness of operators who are engaged in vigilance tasks.

Traditionally, vigilance tasks have been considered as tedious but benign assignments that place little demand on operators, and the decrement function, the decline in efficiency over time that typifies performance in vigilance tasks (Davies & Parasuraman, 1982), has been viewed as resulting from task underload and consequent under arousal (Warm et al., 2008). More recent studies have indicated that while they are tedious, vigilance tasks impose a substantial demand upon the information-processing resources of observers and are highly stressful (Warm et al., 2008).

Neurophysiological evidence of high mental workload in vigilance comes from studies examining brain activity in observers using electroencephalography (EEG; e.g., Gevins & Smith, 2007). EEG research suggests that activity in the 4-7 Hz range, known as theta band activity, reflects extant mental work, and more specifically, that theta activity in the frontal midline region varies directly with task demand. In the vigilance domain, a recent experiment by Berka and colleagues (2007) confirms that theta activity increases during performance of a demanding vigilance task, a result that is consistent with other research that links increases in theta activity with increases in mental workload (e.g., Gevins & Smith, 2007)

The stress associated with vigilance task performance has been extensively investigated using the Dundee Stress State questionnaire (DSSQ; Matthews et al., 2002), a multidimensional scale that measures stress experienced in terms of affect, motivation, and cognition. Studies with the DSSQ indicate that participation in vigilance tasks leads to loss of task engagement and increased feelings of distress (Warm, Matthews, & Finomore, 2008).

Of additional interest to the Air Force is the performance of teams of operators because of the reliance of military functions on teamwork for success. Researchers in this area have examined the role of teams in vigilance performance by comparing the frequency of target detections by teams in comparison to those obtained by operators working alone. In most of these studies, if a target was detected by any member of the team, the team received credit for the correct detection or “hit.” In terms of correct detections, teams of operators have consistently outperformed their single operator counterparts (Bergum & Lehr, 1962; Hornseth & Davis, 1967; Klinger, 1969; Morgan & Alluisi, 1965; Morrissette, Hornseth, & Shellar, 1975; Pollack & Madans, 1964; Wiener, 1964). However, these studies of team performance have focused solely on performance efficiency and have not examined the costs associated with being a member of a team.

Does working on a team affect the degree of workload and stress associated with vigilance performance? The phenomenon of “social loafing” in which operators exert less effort because they trust their associates to support them would lead to the expectation that being on a team would lower operator workload and stress in comparison to working singly. On the other hand, the phenomenon of “social comparison” would lead to the opposite expectation, because underperforming as a member of a team would make an operator look less competent than her/his associates, and consequently might elevate levels of workload and stress. The goal of this study was to use EEG theta activity and the DSSQ to examine the workload and stress associated with performing a vigilance task as a co-operator relative to performing individually.

Method

Participants assumed the role of either a single UAV controller or a member of a dyadic team of UAV controllers. Participants were assigned at random to the single-operator or co-operator conditions. They were instructed to monitor the clockwise or counterclockwise flight pattern of four UAVs on a simulated air traffic control display. The display was divided into four 90° quadrants, each containing one UAV icon. The task of the controller was to look for cases in which two of the UAVs were on a collision path (the critical signal for detection). In either condition, both the clockwise and counterclockwise flight path directions appeared in a random manner throughout the vigil so that a UAV that was at fault in one flight direction was not at fault in the other. Examples of critical and neutral signals can be seen below in Figure 1.

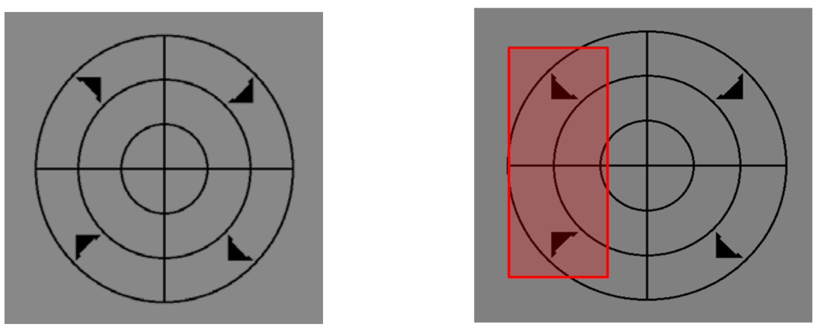

Figure 1. Examples of neutral events and critical signals in the flight path display.

In the single-operator condition, participants performed the vigilance task alone, and were solely responsible for identifying the potential collisions between the UAVs. The co-operator condition used same sex dyads to perform the task. The dyads performed the vigilance task together in an 8 foot × 6 foot room. Although separated by an opaque divider, participants were aware of each other’s presence, and were informed that they would be performing the same task. However, they were instructed not to communicate, collaborate, or strategize with each other, as previous research indicates that team communication could negatively influence team performance by distracting team members from the task (e.g., Bergum & Lehr, 1962). Apart from the direction not to communicate with the other member of the dyad, the co-operators were given identical instructions regarding task mechanics to that of the observers in the individual condition.

Fifteen observers (8 women and 7 men) were assigned to the single-operator condition, while 28 observers (14 men and 14 women) were paired to form the co-operator dyads. All participants served in a 40-minute vigil divided into 4 continuous 10-minute periods of watch. In both conditions, the display was updated 30 times/minute with a dwell time of 1000 msec. Sixteen critical signals occurred during each period of watch (four in each display quadrant, two clockwise and two counterclockwise). In both conditions, participants responded by pressing the spacebar on a computer keyboard. In the single-operator condition, participants were credited with a correct detection if they executed a key-press response in the presence of a critical signal, and were charged with an error of commission (i.e., a false alarm) if they made a key-press response to a neutral event. In the co-operator condition, the *dyadic team* was credited with a correct detection if either member of the dyad detected the target correctly, and the *dyadic team* was charged with a commission error if either member made an inappropriate detection response to a neutral event. A CleveMed 8-channel bio-radio was used to record theta activity from sites F3, Fz, Cz, and Pz, as activity at these sites has previously been linked to mental processing and workload (e.g., Gevins & Smith, 2007). Task induced stress was measured by the DSSQ, which was administered prior to and at the conclusion of the vigil.

Results

Performance efficiency. Mean percentages of correct detections in the single-operator and co-operator task conditions are plotted as a function of periods of watch in Figure 2.

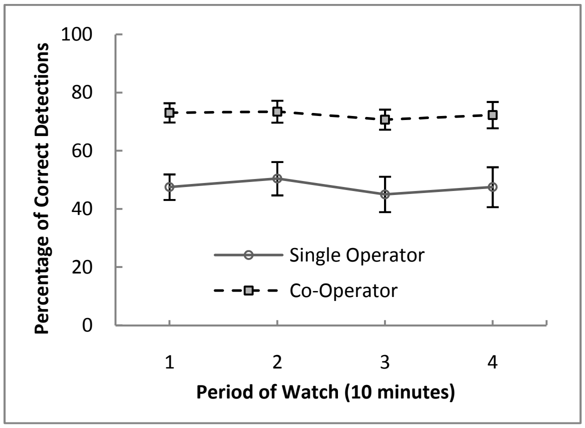

Figure 2. Mean percentages of correct detections in single- and co-operator conditions by periods of watch. Error bars are standard errors.

It is evident in the figure that performance efficiency was greater in the co-operator condition than in the single-operator condition, and that the frequency of signal detections appeared to remain stable over time. These impressions were confirmed by a 2 (conditions) × 4 (periods of watch) mixed-model analysis of variance (ANOVA) of the arcsines of the percentage of correct detection scores (Kirk, 1995), which revealed a significant main effect for conditions, $F(1, 27) = 12.91$, $p < .05$, but not for periods of watch, $F(2.79,75.31) = .71$, $p > .05$. The interaction between these factors was not significant ($p > .05$). In this and all subsequent ANOVAs, the Box correction (Maxwell & Delaney, 2003) was used when appropriate to correct for violations of the sphericity assumption.

An examination of the false alarm scores revealed that errors of commission were rare in this study (i.e., less than 1% of responses). Consequently, these data were not examined further.

Theta activity. Mean recorded theta activity in the co-operator and single-operator conditions by period of watch are represented in Figure 4, below. For purposes of this figure, theta activity data were aggregated across recording sites.

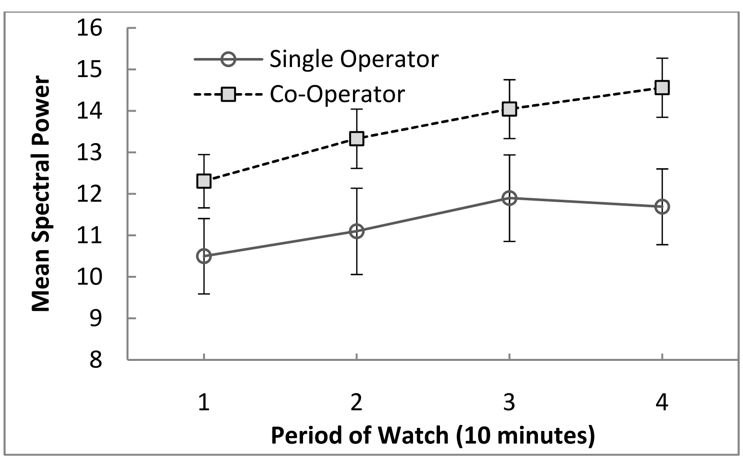

Figure 4. Mean spectral power in the theta band (4-7 Hz), aggregated across recording sites, in the single- and co-operator conditions for each period of watch. Error bars are standard errors.

To analyze theta activity in operators, values were first standardized (z-scored) within each individual across monitored sites. A 2 (conditions) × 4 (periods of watch) × 4 (recording site) mixed-model ANOVA revealed a main effect for condition, $F(1, 41) = 8.23$, $p < .05$, and main effects for period, $F(2.45, 100.30) = 13.89$, $p < .05$, and site, $F(1.89, 77.34) = 228.86$, $p < .05$, along with an interaction between period and site, $F(4.02, 164.73) = 4.73$, $p < .05$. Bonferroni corrected *t*-tests revealed that theta activity increased over time at all sites, and that the greatest activity occurred at sites F3 and Fz. Subsequent testing revealed that while theta levels increased over time at all sites, theta levels in these sites were greater than their counterparts by the final period of the vigil. In addition, as is illustrated in Figure 4 above, overall theta levels were greater in the co-operator condition than in the single-operator condition, and theta activity increased over time. All other sources of variance in this analysis were not significant, $p > .05$. In this analysis and the analysis of the DSSQ data to follow, both members of the co-operator dyads were included. Consequently, the co-operator condition had twice as many subjects as the single operator condition. A type III sum of squares was utilized to compensate for the unequal *N* (Field, 2009).

DSSQ stress state. For all observers in the co-operator and single-operator task conditions, pre- and post-vigil DSSQ scores for the worry, task engagement, and distress factors of the DSSQ were standardized against a large normative group with a mean of zero and a standard deviation of one (Matthews et al., 2002). Task-related difference scores were obtained by subtracting the pre-task score from the post-task score. Separate one-way ANOVAs were then computed for each of the three DSSQ factors. A statistically significant difference between conditions was found for the distress dimension, $F(1, 41) = 9.43$, $p < .05$. Analysis of the data for the worry and engagement dimensions revealed no statistically significant differences between conditions, $p > .05$. Mean standardized difference scores (change scores) for all combinations of task condition, period of watch, and DSSQ factors are represented graphically in Figure 3. As is evident in the figure, observers showed little post-vigil change in worry, but they reported themselves as being less task-engaged and more distressed after the vigil than before its start. It is also clear in the figure that participants in the single-operator condition reported a far greater increase in distress (more than 1 standard deviation) than did participants in the co-operator condition.

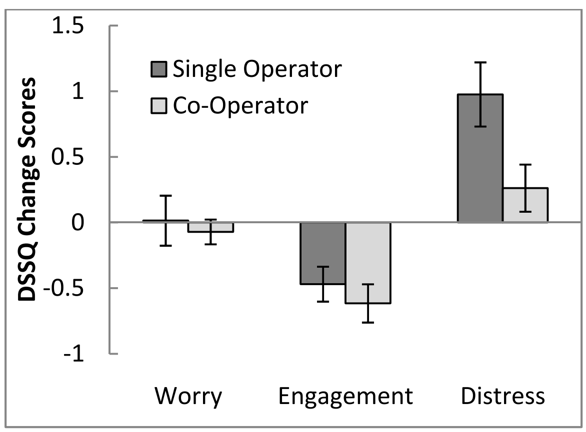

Figure 3. Mean DSSQ change scores for all factors by condition. Error bars are standard errors.

Discussion

As in several previous vigilance studies, co-operator performance in terms of correct detections exceeded that of operators working alone (Bergum & Lehr, 1962; Hornseth & Davis, 1969; Klinger, 1969; Morgan & Alluisi, 1965; Morrissette, Hornseth, & Shellar, 1975; Pollack & Madans, 1964; Wiener, 1964). As noted above, however, those earlier studies made no attempt to determine the cost to observers in terms of workload and stress associated with team membership. The purpose of the present study was to fill that gap in the tapestry of team performance in vigilance. A "social loafing" model led to the expectation that because of task dynamics both workload and stress would be less in the co-operator than in the single-operator condition. Conversely, a "social facilitation" model led to the expectation that workload and stress would be greater in the co-operator condition compared to single operators. The results supported neither model completely.

Consistent with expectations about workload derived from the "social facilitation" model, activity recorded within the theta band signified that participants in the co-operator condition exhibited higher levels of activity, indicating that they devoted more cognitive resources to maintaining their performance levels, and experienced greater mental workload in consequence. This may have been due to a sense of competitiveness, feelings of responsibility to the team, or general feelings of motivation associated with working as a member of a dyad.

With regard to stress, observers in both task conditions demonstrated a loss of task engagement over time, a result that is characteristic of previous vigilance studies using the DSSQ (Warm et al., 2008). However, in addition to the loss of task engagement, observers in the single-operator condition indicated a greater increase in distress after participating in the vigil than did those in the co-operator condition. Rather than accounting for this effect in terms of "social loafing" it is more likely that, given the higher neurophysiological workload scores observed, participants in the co-operator condition experienced less distress because of their knowledge of the "safety net" provided by a teammate.

Overall, these results suggest that military operations which require long periods of sustained attention from operators, such as in UAV surveillance, could be substantially benefitted in terms of increased task performance by the adoption of dyadic teams of operators, and that such benefit will not come at the cost of increased stress to the operators involved. This finding is valuable as increased stress would likely negate the utility of adopting dyadic teams because of the negative effects that stress exerts on the wellbeing and eventual performance of team members (Matthews et al., 2002).

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